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FIBER OPTICS IN NEUTRAL BEAM CONTROL ON THE TMX EXPERIMENT AT LLL

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G. G. Pollock, Lawrence Livermore Laboratory, Livermore, CA 94550-The neutral beams on the TMX experiment make extensive use of fiber optics for control and monitoring. Over 200 individual links are used, spanning a wide range of lengths, data rates, and implementation techniques. The objectives of high voltage isolation, EMI immunity and ground loop avoidance were successfully achieved. The fiber optics introduced some problems of their own, principally in mechanical survival of the fibers and in posing subtle interdisciplinary problems to designers. This paper will describe the various types of lines used and their implementation. Problems unique to fiber optics and alternative approaches will be discussed.

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Summary

The neutral beams on the Tandem Mirror Experiment (TMX) experiment make extensive use of fiber optics for control and monitoring. Over 200 individual links are used, spanning a wide range of lengths, data rates, and implementation techniques. The objectives of high voltage isolation, EMI immunity, and ground loop avoidance were successfully achieved. The fiber optics introduced some problems of their own, principally in mechanical survival of the fibers and in posing subtle interdisciplinary problems to designers. This paper describes the various types of lines used and their implementation. Problems unique to fiber optics and alternative approaches are discussed.

Introduction

The Tandem Mirror Experiment (TMX) is a major fusion energy experiment built during 1978 at LLL. Early in the planning phases of the experiment, a major commitment was made to utilize the emerging technology of fiber optics to provide high voltage isolation and EMI immunity for the control and monitor circuits associated with TMX's 24 neutral beams. At the completion of TMX construction, 264 fiber optic links had been installed. These links covered much of the spectrum of the technology. Their lengths ranged between 1 and 55 m. Some were complex, transmitting phase-encoded serial messages, while others were simple, transmitting slow data and imprecise timing at baseband. Both plastic and metal connectors were used as were both single fiber and multifiber bundle cable. While the several designers involved used different techniques in their fiber optics applications, all the links were built from components.

The fiber optics industry is much more mature now than it was in the 1977-78 period when these designs were made. Today, we would probably select from among the many modular systems available rather than build from components. However, being forced to build from components held the virtue that we had to deal with the technology on its most atomic level and become thoroughly conversant with the various disciplines involved. Although we might implement our links differently today, most of the lessons and experiences from the construction of this large and diverse system of fiber optics remain valid.

Development History

The system requirements that led to the large application of fiber optics were high voltage isolation and EMI immunity for the control and instrumentation of TMX's 24 neutral beams. The processes involved take place at 20 to 40 kV above ground, and the neutral beams themselves are the source of a very high EMI environment. Large ground potential differences are to be expected as well. These problems had been previously attacked with a patchwork of approaches. EMI was handled with a generous application of coaxial cable, conduit, common mode chokes, filters, and transient suppression networks. High voltage isolation was achieved by a variety of ad hoc techniques. Typical was the system used to bring high bandwidth instrumentation signals down from high voltage. This system was battery-powered, analog optical telemetry through short lengths of glass rod. While it did provide high voltage isolation, the output signal had poor accuracy and was trusted only as a qualitative indicator.

In 1977 when the design approaches for TMX were being decided, fiber optics had matured to the point where it appeared to be a reasonable alternative solution to the problem of high voltage isolation and EMI survival. Although there were practically no modular systems available that were suitable to our purpose, there were at least a number of manufacturers of components.

Our initial entrance into fiber optics was an effort to develop a replacement for the glass rod, high voltage telemetry system described earlier, basing our initial work on a system being built in the laser fusion group at Los Alamos.

During this development, a decision was made to attempt to build a system whose maximum link lengths would be capable of reaching from the point of signal origin all the way to the control room, a distance of 18 to 55 m. Thiswould offer us a total solution to the problem of EMI pickup on instrumentation cables and considerably simplify installation, since the shielding of solid conduit would be unnecessary and our fiber optic cables could be simply laid in troughs and cableways. The system that resulted had a calculated maximum link length more than three times the maximum length required.[1]

Other TMX designers developed three other fiber optic link systems, largely using the same components as selected for telemetry. One was an inexpensive low bandwidth system whose maximum length was the same as for the telemetry system. A variation of the telemetry system was developed for high bandwidth timing data. Finally, a short length system for power supply internal use was developed.

Anatomy of a Fiber Optic Link

Before describing the specific links used in the TMX, it is useful to describe the structure of a basic fiber optic link. While not all fiber optic links possess all of the functions shown, Fig. 1 illustrates the functions required in the most general expression of a fiber optic system.

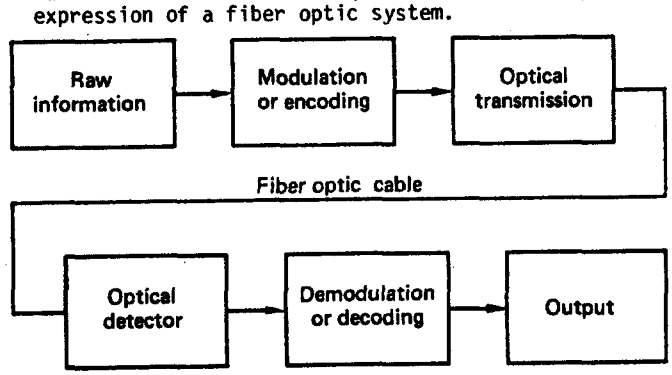

Figure 1

General Optic Fiber Link

The raw information to be transmitted is first modulated or encoded. Modulation or encoding is a process that takes the data in the form which is suitable to the originator and transforms it into a form suitable for transmission over the media. In some cases, modulation or encoding is used to combine the basic signal with clock information and serial message frame synchronizing information. In other cases, modulation or encoding are used to make a baseband signal suitable for transmission through a media that does not conveniently extend down to dc.

The modulated or encoded information is next optically transmitted. Optical transmission consists of transforming of the electrical signal to an optical signal of suitable wavelength for coupling into the fiber optic cable and the necessary connectors to accomplish the coupling.

The next element of the typical fiber optic link is the fiber optic cable. At the receiving end of the fiber optic cable is an optical detector, which transforms the optical signal back into an electronic signal.

The final process is a demodulator or decoder that reconstructs original form of the data from the detected optical signal.

Link Details

Telemetry Link

The telemetry link was the first fiber optic link developed for the TMX project. It consists of three, high-speed analog telemetry channels for each neutral beam. Each channel telemeters a 0-to 10-V analog signal with a resolution of 8 bits and a sample rate of 200 K/s from the point of measurement to the control room. The analog signal to be transmitted is passed through signal conditioning amplifiers and digitized by an 8-bit analog-to-digital converter. The digitized signal is serialized and encoded using biphase modulation. The biphase representation of the signal is transmitted by a simple TTL peripheral driver circuit and connector-mounted, high-speed infrared LED through the fiber optic cable to the control room (18 to 55 m) at a bit rate of 2 megabits/s. In the control room a hybrid integrated circuit photo detector is used to detect the optical signal. The biphase signal is then decoded, converted to parallel data, and transformed to an analog signal representing the remote measurement.

The biphase system of modulation or encoding was selected for this link for several reasons. First, it provided a means for sending serial digital data combined with its own clock signal and serial message frame synchronizing signal. Second, biphase modulation has the property that over a very short time interval it has a 50% duty factor. This is important to the thermal equilibrium of the transmitting diode. It is also important to the receiving system which, to account for the large drift in the dc component of the hybridreceiver output, must be ac coupled. A further advantage is that the infrared LED may be driven at pulse mode ratings rather than continuous ratings, with a corresponding increase in peak optical output.[2]

Arc Pulse Timing Link

The arc timing link is a close relative of the telemetry system and is based on many of the same design components. The arc timing link transmits submicrosecond quality timing information to the neutral beam arc power supply system. The receiver design is modified so that rather than being an ac-coupled biphase detector, it is a differentiating edge detector responding to the positive and negative transitions of very low duty factor timing pulses.

Slow Long Links

There were a number of applications in the TMX system for which data rate could be traded for complexity. A design was developed that was considerably simpler than the telemetry system design, which allowed the transmission of low speed data over links which were equally long. Such links transmit low baud rate serial data, voltage to frequency converted analog measurements, and simple binary information. The same transmitter is used as in the high speed links, but the receiver is a simple circuit employing a phototransistor detector. The slow links that transmit low baud rate serial data and binary information employ a simple frequency shift modulation scheme to give the same 50% duty factor advantages described for the telemetry link.

Short Links

Within the accel/decel supply of a TMX neutral beam, there is a requirement to take control signals from ground level equipment to the high voltage deck of the accel regulator. This is an internal connection whose length is typically only 1 m. A very simple system was designed using multifiber-bundled cable and simple transmitting and receiving circuits to provide the high voltage standoff required within this chassis. The transmitting diodes are inexpensive lensed units normally sold for other purposes. The receivers employ a higher gain, medium bandwidth version of the same hybrid optical detector used in the telemetry and arc timing systems.

Components Selected

Cables and Connectors

Perhaps the most critical choice in the construction of a fiber optic system is that of the cable and the connector combination. For the short lengths within the accel/decel supply, the cable selected was a high numerical aperture, large diameter multifiber bundle, Gallite 2000[3]. Because there is no mechanical stress on these internal cables, simple plastic connectors (AMP) were used. For the external links, a large diameter, single fiber, moderately low loss cable was selected (Valtec PC10-01). The large diameter of the single fiber provides a large enough light aperture so that a significant amount of power can be coupled using simple planar light emitting diodes. The cables moderately low loss is the factor that allows link lengths (calculated) to approach 175 m for the long links, more than three times our requirement.

The Amphenol 905 series metal connector system is used with this cable. This allows us to fully utilize the high tensile strength of the cable, provides shielding for the sensitive detector, and provides effective heat sinking for the transmitting diode. Transmitting diodes and detectors are mounted directly in bulkhead connectors.

Emitters

For the short links within the accel decel supply, low priced lensed infrared LED's were used. For all long links, the diode used was a gallium arsenide, infrared LED with a 4 mW output at a wavelength of 890 nm.

Detectors

For the slow speed long links, the optical detector was a simple phototransistor. In both the short links within the accel/decel supply and the long telemetry and arc timing links, the optical detector was a hybrid opticaldevice made by the Devar Company, consisting of a back biased PIN photodiode and high-gain bandwidth operational amplifier in a common TO5 package. This packaging technique protects the most sensitive parts of the detector circuitry from external noise and avoids loss of amplifier bandwidth due to stray capacitance. The receiver circuits were based upon this hybrid integrated circuit in combination with buffer amplifiers and comparator detectors.

Fiber Optic Experiences from TMX

Installation and Cable Damage

There are no electrical reasons to install fiber optic cable in conduit. There are many alternate methods of providing the simple mechanical protection required. Nevertheless, conduit is a traditional form of cable installation in the LLL/MFE area, and many of our fiber optic cables were installed partly through runs of conduit by electricians. Although the cable material used has a tensile strength of 150 lb, a large amount of cable damage occurred during initial installation. This cable damage was in almost all cases found to be within a short distance of one end or the other. Cable damage tended to not be caused by exceeding the yield strength of the cable, but by kinking or crushing in conduit pull boxes or in control room racks. Unfortunately, our initial orders of fiber optic material tended to look very much like common coaxial cable, and they were treated by the installers and users in much the same way. Fiber optic cable will not tolerate the abuse that coaxial cable will and the result was considerable damage at the exposed user ends of the cable. Fiber optic cables were found on occasion to be laid across aisleways, crushed in rack doors, and unbelievably knotted in the wiring in the backs of control room racks. It was not until the fiber optic system developed a reputation for being fragile that the technicians and installers developed a proper respect for the material being handled. We have adopted the practice of the LLL High Voltage Test Stand project and order our material with a bright orange jacket so that it is easily distinguished.

Cable damage is directly related to the amount of cable handling involved in installation and normal use. In the case of TMX, the cables are connected at both ends directly to the chassis that originates or receives the signal. This causes more cable handing on initial installation, since there are many sources and destinations. The amount of cable handling remains high in normal use, since fiber optic cables must be disconnected each time a chassis is removed for maintenance. A better approach would be to centralize the fiber optic transmitters and receivers into special chassis and communicate from them with wire to the actual sources and destinations.

Test Equipment

When installing any system of this size, the designer should insure he has proper test equipment. We found two devices useful. The first, made from spare parts from our own links, was a simple device that could detect a broken cable and make an estimate of the optical loss in an installed cable. We normally used this simple instrument to screen large numbers of cables to determine those were within normal performance limits and those that had suffered installation damage and needed repair. The second instrument, an optical time domain reflectometer, was used to determine the location of the damage on cables needing repair. While this instrument is an expensive item, its cost is justified on a project with many fiber optic cables.

The Sole Source Problem

It is an unavoidable hazard in working with a technology as new as fiber optics that one must deal with companies whose products are not interchangeable with those of their competitors. The designer is inevitably led into taking his best chance with a sole source supplier of critical system components. In TMX, the critical, sole source component was the transmitting infrared LED, which offered an excellent combination of high power output, good coupling geometry, desirable wavelength, and economical cost. Regrettably, the company supplying this item is no longer in business. This has forced us into a minor link redesign to accommodate devices that are only approximately equivalent manufactured by competitive companies. While the industry situation today is far better than when TMX was built, there is still a problem of interchangeability between manufacturers, especially in modular systems.

Recognition of an Interdiscipline Problem

One of the subtle problems in the utilization of fiber optics is that it crosses many disciplines. This fact is very apparent when one is dealing at the component level. Analog electronics, digital electronics, coding, modulation, and optics are all important in the design of a useful fiber optic system. It is a mistake to believe that any of these subjects can be ignored. In today's environment of available modular systems, the hazard is even greater because the unwary designer may use of such systems without understanding all the questions that must be asked of a specification. For example, most detection systems exhibit a very strong temperature coefficient of their dc component and are therefore ac-coupled. It is the practice, however, for manufacturers of modular systems to specify the bandwidth in terms of the NRZ data rate. NRZ is a digital coding system whose spectrum extends to dc, is strongly data dependent, and inappropriate for use on many fiber optic links. Although the industry has changed and many modular systemsare available (relieving the user of the necessity of dealing with fiber optics at the components level), the obligation of the potential user to thoroughly acquaint himself with all aspects of fiber optic link design has not changed.

Conclusions

The TMX fiber optics systems achieved their objectives of high voltage isolation and EMI immunity. While there have been the expected problems in being early users of a new technology, the benefits are far more important and we will make extensive use of fiber optics in future systems.

Acknowledgements

I would like to acknowledge the contribution of Kent Nielson to the original system development.

References

1. G. G. Pollock, "TMX Fiber Optic Telemetry System", LLL Memorandum FE77-09-13.
2. G. G. Pollock, "A Data Coding System for Fiber Optic Communications", LLL Memo FE77-06-46.
3. Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the Department of Energy to the exclusion of others that may be suitable.